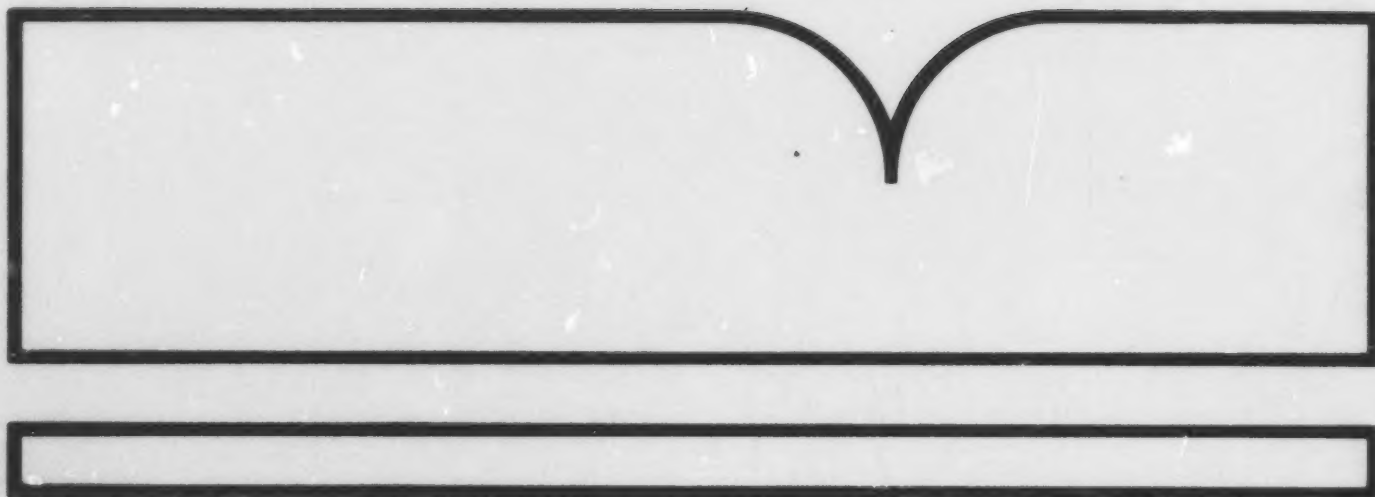


PB86-177797

Comparative Removal of Toxic
Pollutants by Six Wastewater
Treatment Processes

(U.S.) Environmental Protection Agency
Cincinnati, OH

1986



U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA/600/J-86/018	2.	3. RI PB 86-177797
4. TITLE AND SUBTITLE Comparative Removal of Toxic Pollutants by Six Wastewater Treatment Processes (Journal Version)	5. REPORT DATE 1986	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Sidney A. Hannah, Barry M. Austern, Atal E. Eralp and Robert H. Wise	8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Wastewater Research Division Water Engineering Research Laboratory 26 W. St. Clair St. Cincinnati, OH 45268	10. PROGRAM ELEMENT NO. AJWB1A, Task 01	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory--Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Final 12/83 - 8/84	14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES Project Officer - Sidney A. Hannah 513/684-2621 REF: Journal WPCF, 58(1):27-34, January 1986		
16. ABSTRACT Five pilot scale wastewater treatment processes providing less than secondary treatment were evaluated for capability to remove priority pollutants from municipal wastewater. The selected processes were primary clarification plus filtration, chemical clarification, high rate trickling filter, aerated lagoon and facultative lagoon. A conventional activated sludge system was operated in parallel with the alternative processes to serve as a control. Wastewater feed was spiked with 21 organics dissolved in toluene. Removals of ambient levels of five metals were also determined. The control activated sludge provided the best removals of organics; typically 80 - 90% of volatiles and 85 - 95% of semivolatiles. The facultative lagoon was the best alternative process followed by the aerated lagoon. Removals of a specific toxic pollutant depended upon the properties of the chemical and its interactions with the removal mechanisms presented by each treatment process.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
activated sludge, chemical clarification, filtration, metals, organics, primary, toxics, trickling filter, wastewater	Sewage Treatment Water Pollution	13B
18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (T=Report) Unclassified	21. NO. OF PAGES 9
	20. SECURITY CLASS (T=Page) Unclassified	22. PRICE



Comparative removal of toxic pollutants by six wastewater treatment processes

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Sections 301(h) and 403(c) of the Federal Water Pollution Control Act set permit requirements and ocean discharge criteria that apply to permits for discharge of wastewaters into marine waters. Complete secondary treatment, which is normally required for wastewaters discharged to inland waters, may not be necessary to meet ocean discharge criteria. Alternative treatment processes that produce a lower quality effluent at a substantially reduced cost have been suggested as substitutes for secondary processes. The objectives of this study were to evaluate selected pilot-scale alternative treatment processes designed to provide less-than-secondary treatment for removal of toxic pollutants, and to determine how the toxics partition and interact within the processes.

The U. S. Environmental Protection Agency (EPA) has published proposed water quality criteria to protect saltwater aquatic life from acute or chronic toxicity, and to protect humans from the toxic properties of pollutants ingested through contaminated aquatic organisms.¹ Table 1 lists the proposed criteria for 21 volatile and semivolatile organic priority pollutants and five metals representative of toxic pollutants in municipal wastewaters. A survey of 50 publicly owned treatment works for priority pollutants² showed that influent wastewater concentrations at one or more of the plants exceeded the criteria for 13 of the 21 listed organic pollutants and four of the five metals.

Alternatives to the activated sludge process do not remove toxics as well, but may be useful where removal requirements or water quality criteria are not overly restrictive.

Processes chosen as having greatest potential application for 301(h) permits were single-stage high-rate trickling filter, primary treatment with chemical addition, direct filtration of primary effluent, aerated lagoons, and single-stage facultative lagoons. A conventional activated sludge system was operated in parallel with the alternative systems to provide a control against which the alternative systems could be compared. Influent wastewater was spiked with 21 listed priority pollutant organics dissolved in toluene. Because ambient concentrations of the five metals in the influent wastewater were sufficiently high, spiking of metals was not required. Samples of feed, effluents, and sludges were analyzed for both conventional and priority pollutants. This report discusses the results of the study conducted by the Water Engineering Research Laboratory at the Test and Evaluation (T&E) Facility, Cincinnati, Ohio. Petrasek *et al.*^{3,4} reported removals of metals and organics by activated sludge treatment at this facility.

Samples of feed and effluents were also collected to assess toxicity reduction through treatment; 7-day subchronic tests with fathead minnow and chronic tests with *Ceriodaphnia* were used. Results of those tests were reported elsewhere.⁵

PILOT PLANT SYSTEMS

The four biological treatment systems were operated on spiked wastewater for 30 days before the first samples were collected. This permitted the biomass to acclimate to the added toxics. The systems operated continuously on spiked wastewater after startup to maintain the biomass in an acclimated condition. The primary with chemical addition system and the high-flow direct filtration of primary effluent system were operated only during scheduled sampling periods to reduce the cost of spiking chemicals and associated labor in spike concentrate preparation.

Pretreatment. Raw wastewater at the T&E Facility, pumped from the adjacent Mill Creek Wastewater Treatment Plant, is of relatively high strength with a 14-month average (May 1982 to June 1983) of 279 mg/L biochemical oxygen demand (BOD) and 487 mg/L total suspended solids (TSS). Mill Creek secondary effluent was passed through a bed of granular activated carbon and used to dilute the raw wastewater 1:1 to provide pilot system wastewater feed concentrations that are more typical of domestic U. S. wastewater. Average concentrations of conventional pollutants in the feed are shown in Table 2.

Two steel columns 74 cm inside diameter (ID) and 3.7 m high, each containing 1.5 m depth of 8 × 30 mesh granular activated carbon were used to treat the Mill Creek secondary effluent. One column normally operated with the other in backwash or standby mode. The carbon was not regenerated during the 8-month study. An equal volume of coarse-screened raw wastewater was mixed with the carbon column effluent, and the spiking solution of 21 priority pollutant organics in toluene was pumped into the combined wastewater to provide 100 µg/L of each priority pollutant. Fifty µg/L of both lindane and heptachlor were added only during the last 2 months of the study. The organic priority pollutants are listed in Table 1. The spiked wastewater contained 70 mg/L toluene.

The resulting spiked wastewater was passed through a static mixer into three closed detention tanks arranged in series to provide time for the priority pollutants to equilibrate with solids in the wastewater. Detention times ranged between 1.2 and 5.6 hours depending on the number of pilot systems in operation. To prevent solids from depositing in the detention tanks at low flows, effluent from the third tank was pumped through a recirculation line back to the first tank. The spiked equilibrated wastewater was pumped from the recirculation line to feed all systems. Samples of raw wastewater, carbon column effluent,

Table 1—Proposed water quality criteria for protection of both salt-water aquatic life and human health.

Proposed water quality criteria, µg/L			
Pollutant	Aquatic life protection		Human health criteria
	Acute	Chronic	
Volatiles			
Carbon Tetrachloride ^a	50 000	—	6.94 ^b
1,1 Dichloroethane	—	—	—
1,1 Dichloroethylene ^a	224 000	—	1.85 ^b
Chloroform ^a	—	—	15.7 ^b
1,2 Dichloroethane ^a	113 000	—	243 ^b
Bromoform ^a	12 000	6 400	15.7 ^b
Ethylbenzene ^a	430	—	3 280
Semivolatiles			
Bis(2-ethylhexyl)phthalate	2 944	—	50 000
Dibutylphthalate	2 944	—	154 000
Naphthalene	2 350	—	—
Phenanthrene ^a	300	—	0.0311 ^b
Pyrene ^a	300	—	0.0311 ^b
Fluoranthene ^a	40	16	54
Isophorone	12 900	—	520 000
Bis(2-chloroethyl)ether ^a	—	—	1.36 ^b
p-Dichlorobenzene	1 970	—	2 600
Phenol	5 800	—	—
2,4 Dichlorophenol	—	—	3 090
Pentachlorophenol ^a	5	3	1 010
Lindane ^a	0.16	—	0.0625 ^b
Heptachlor ^a	0.053	0.0036	0.00029 ^b
Metals			
Chromium, CrIII	10 300	—	3 433 000
Copper, Cu ^a	23	4	—
Nickel, Ni ^a	140	7.1	100
Lead, Pb ^a	668	25	—
Cadmium, Cd ^a	57	4.5	—

^a Compound's for which influent wastewater concentrations in POTW survey exceeded one or more of the listed water quality criteria.

^b Carcinogen. Level that may result in incremental increase of lifetime cancer risk of those exposed by one in a million.

and spiked feed were analyzed for conventional and priority pollutants along with effluents and sludges from the treatment systems.

Conventional activated sludge system. The control activated sludge system was operated at 8.2 m³/d (1.5 gpm). The primary clarifier is a circular stainless steel tank with a 45° conical bottom. The inside diameter is 0.91 m and the sidewater depth is 1.5 m. There is a 0.3-m diameter inlet well and a sludge collector that operates at 5 rph. Overflow rate for the clarifier is 12.4 m³/m²·d, and hydraulic detention time is 3.2 h at design flow. The aeration basin is a five-pass rectangular, stainless steel tank 3.05 m long and 0.61 m wide with a sidewater depth of 1.37 m.

Table 2—Average concentrations (mg/L) of conventional pollutants in wastewater feed to pilot treatment systems.

TSS	Total COD	Soluble COD	TKN	NH ₃ -N	NO ₂ -N	NO ₃ -N	Total phosphorus
164	344	172	20.9	12.7	0.25	0.15	3.6

Residence time is 7.5 h at design flow. The final clarifier is identical to the primary clarifier.

The return activated sludge (RAS) was 2.7 m³/d (0.5 gpm) or one third of the influent flow. The suspended solids concentrations in the mixed liquor and RAS were approximately 2000 mg/L and 7000 mg/L, respectively. The activated sludge system was operated at a nominal solids retention time of 7 days, which resulted in a food-to-microorganism ratio (F/M) of 0.5 kg chemical oxygen demand (COD) per day per kilogram of mixed liquor suspended solids (MLSS). The activated sludge system removed an average of 93% TSS. Removals of total COD and soluble COD were 82% and 69%, respectively. Nitrification, which occurred throughout the study, reduced the influent ammonia an average of 86% and the total Kjeldahl nitrogen (TKN) by 80%. Effluent nitrate nitrogen plus nitrite nitrogen (NO₃-N + NO₂-N) averaged 8.0 mg/L. Total phosphorus was reduced by 58%. Of the processes evaluated, the activated sludge produced the best overall treatment. It was the only process that significantly reduced ammonia in the wastewater.

High rate trickling filter system. The 8.2 m³/d (1.5 gpm) high-rate trickling filter system consists of a primary clarifier, a trickling filter, and a final clarifier. The two clarifiers are identical to

those described for the activated sludge system. The trickling filter is a circular steel tank, 2.4 m high with a 0.91-m ID, which contains 1.9 m of 3.8 to 7.6-cm (1.5 to 3 in.) crushed slag media. Primary effluent and return flow from the bottom of the trickling filter are applied to the media from a motor-driven rotating distributor arm. The return flow is adjusted to 8.2 m³/d, equivalent to 100% of the design wastewater flow. Based on design wastewater flow, the surface application rate to the filter is 12.4 m³/m²·d, while the application rate for the volume of media is 6.6 m³/m³·d.

The high rate trickling filter system removed 76% of the influent TSS, but only 47% of COD and 26% of soluble COD. TKN was reduced by 14%; total phosphorus was reduced by 39%.

Primary treatment with chemical addition. The 10.9-m³/d (2-gpm) chemical addition system consists of a rapid-mix tank where alum solution is flash-mixed with the wastewater, a flocculation tank where gentle agitation produces a settleable floc, and a final clarifier where the solids are separated from the wastewater. The rapid-mix tank is constructed of stainless steel and has a 29.5-cm ID and a 8.9-cm liquid depth. It is equipped with a propeller mixer and has a detention time of 48 seconds at design flow. The rectangular steel flocculation tank is 0.6 m wide by 1.4 m long and has a water depth of 0.4 m. It is equipped with two paddle stirrers and has a detention time of 52 minutes at design flow. The steel clarifier is 0.95 m ID and has a 1.45-m sidewater depth. The overflow rate is 15.2 m³/m²·d. Alum stock solution (19 g/L) is prepared in stainless steel drums by dissolving commercial filter alum in tap water. This solution is pumped to the rapid-mix tank at a constant dosage of 250 mg/L in the wastewater.

The chemical treatment system removed 89% of influent TSS to produce a relatively clear effluent. Alum precipitation of phosphorus reduced total phosphorus by 75%. The system reduced COD, soluble COD, and TKN by 49%, 2%, and 12%, respectively.

Direct filtration of primary effluent. Primary effluent is produced when spiked wastewater is passed through a circular steel tank with a 2.3-m ID and a 2.7-m sidewater depth. Detention time is 3.9 hours and overflow rate is 17.0 m³/m²·d at a wastewater flow of 69.8 m³/d (12.8 gpm). The filter that receives the primary effluent is a commercial pulsed-bed pilot unit. This filter uses a 0.25-m bed of 0.35-mm sand as media. The surface loading rate at 54.5 m³/d (10 gpm) flow is 147 m³/m²·d.

The primary plus filtration system removed 86% of TSS, 40% of COD, 15% of TKN, and 44% of total phosphorus.

Lagoon systems. The aerated and facultative lagoons are constructed from sections of concrete pipe, 2.3-m ID. The sidewater depth is 1.2 m, surface area is 4.1 m², and wastewater volume is 4.8 m³. Each lagoon has fourteen 96-in. 5000°K fluorescent lamps suspended 1.8 m above the water surface. The lights are turned on for 14 hours daily.

Wastewater is fed to the lagoons by transfer pump from a 0.19-m³ batch tank. The facultative lagoon receives 0.19 m³ once a day, while the aerated lagoon receives 0.19 m³ four times a day. The hydraulic detention times of the facultative and aerated lagoons are 25.6 days and 6.4 days, respectively. The aerated lagoon is equipped with a perforated pipe sparger attached to the pilot plant compressed air line.

Because of the small size of the lagoon and the absence of a settling compartment, only low air flow rates that were approx-

imately equivalent to the influent BOD could be used to avoid carryout of settleable solids. The air flow was 835 L/d. Dissolved oxygen concentrations in both lagoons, measured 0.3 m below the surface, generally ranged from 0.1 to 0.2 mg/L.

The facultative lagoon removed 84% of TSS, 65% of COD, 42% of soluble COD, 11% of TKN, and 31% of total phosphorus. The aerated lagoon removed 85% of TSS, 60% of COD, 42% of soluble COD, 2% of TKN, and 19% of total phosphorus. While algae blooms occurred periodically in the lagoons, performance was not significantly affected. With their relatively long detention times, the two lagoons produced the best effluents of all the alternative processes but were less effective than the activated sludge control in removing conventional pollutants.

Sample collection and analysis. Twenty-four hour composite samples of process streams prepared from grab samples collected six times per day were analyzed every other day for conventional pollutants using the standard U. S. EPA methods⁵ listed in Table 3. One set of 24-hour composite samples was analyzed for metals each week. Additional grab samples were analyzed three times per day for pH and alkalinity and once daily for solids to control the activated sludge process. All samples were refrigerated at 4°C until analyzed, and sample preservatives were used as permitted by the standard methods.

Samples were collected for 2 or 3 consecutive days at approximately 6-week intervals for organic priority pollutant analyses. Grab samples for volatile analysis were collected three times per day in screw-cap glass vials with an inert fluorocarbon polymer-lined septum. Initially, these grab samples were analyzed individually by the U. S. EPA purge-and-trap technique (Method 1624⁷) but a growing backlog of samples made it necessary to composite chilled grab samples into a single daily composite before analysis. Samples were composited in a 4°C room. The contents of the three vials were gently poured down the side of a chilled Erlenmeyer flask. The flask was gently swirled, and its contents were added to the overflow level of one of the three vials. Analyses of multiple samples that were spiked with known concentrations of priority volatile organics before compositing did not show any losses caused by the nonstandard compositing

Table 3—Analytical methods for conventional pollutants and metals.

Parameter	Method ^a	Description
TSS	160.2	Glass filter, 102° to 105°C
Total COD	410.4	Automated dichromate reflux
Soluble COD	410.4	Glass filter automated dichromate reflux
TKN	351.2	Semi-automated block digestion
NH ₃ -N	350.1	Automated phenolate
NO ₂ -N	353.1	Automated hydrazine reduction
NO ₃ -N	353.1	Automated hydrazine reduction
TP	365.4	Semi-automated block digestion
pH	150.1	Electrode
Alkalinity	310.1	Manual titration
DO	360.1	Membrane electrode
Cr	218.2	Atomic absorption, furnace
Cu	220.2	Atomic absorption, furnace
Ni	249.2	Atomic absorption, furnace
Pb	239.2	Atomic absorption, furnace
Cd	213.2	Atomic absorption, furnace

Table 4—Reproducibility of duplicate analyses of individual collected samples and analyses of samples collected in duplicate—volatiles.

Compound	Average % deviation from mean	
	Duplicate analyses of 27 samples	Analysis of 13 duplicate samples
Carbon tetrachloride	5	24
1,1 Dichloroethane	6	7
1,1 Dichloroethylene	13	19
Chloroform	5	3
1,2 Dichloroethane	8	11
Bromoform	4	15
Ethylbenzene	9	9

procedure. Grab samples were collected six times per day and composited into one daily sample for semivolatile organics analysis, following EPA Extraction Method 1625.⁸

All samples were spiked with a mixture of deuterated or ¹³C-labeled priority pollutant organics to represent the priority pollutants spiked into the wastewater feed. Analytical results for the nonlabeled priority pollutant organics were corrected automatically for the recoveries of the labeled priority pollutant organics. The isotopically labeled compounds were used as internal standards for the corresponding priority pollutants. Furthermore, percent recovery of the labeled compounds, and by inference, of their corresponding natural-isotope analogs, was measured as a function of an internal standard added just before gas chromatography-mass spectrometry (GC/MS) analysis: *para*-Bromofluorobenzene for Method 1624, and anthracene-d₁₀ for Method 1625. A capillary column was used in the GC/MS procedure. Both instruments were attached to a computer data system. To ensure precision, duplicate analyses of individual collected samples and analyses of samples collected and processed in duplicate were performed.

EXPERIMENTAL RESULTS

Volatiles. Precision data from duplicate analyses of individual collected samples and from analyses of samples collected in duplicate are shown in Table 4. The average percent deviation from the mean for each sample pair was averaged with data

from the other sample pairs for each priority pollutant for all feed and effluent samples. Sludge data were not included. The mean percent deviation for duplicate analyses of the same samples for all volatiles was 7%. Variability was somewhat greater for analyses of samples collected in duplicate showing a mean deviation for all volatiles of 13%. The corresponding mean percent deviations for all volatiles in sludge samples was 15% for duplicate analyses and 16% for duplicate samples.

Average concentrations of volatile priority pollutant organics in wastewater feed and process effluents are shown in Table 5. The variability of concentrations in the wastewater feed and primary effluent was relatively high because there were numerous priority pollutants in the incoming raw wastewater. Variability decreased as removal efficiency of the treatment processes increased.

Table 6 shows the average percent removal of each volatile organic calculated from 14 matched pairs of influent and effluent samples. An overall percent removal of volatiles for each process was calculated by averaging the removals of the individual organics. The facultative lagoon and the activated sludge had the best results; both generally exceeded 80% removal. Primary clarification, chemical clarification, and primary plus filtration had little effect on the volatiles. The trickling filter and the aerated lagoon produced intermediate removals.

Table 7 lists concentrations of volatile organics in four sludges from the pilot systems. The concentrations in sludge were generally comparable to or less than the corresponding concentrations in process effluents, an indication that volatile organics do not have a high affinity for wastewater solids and, therefore, do not concentrate in the sludges. A possible exception is the ethylbenzene. Concentrations in the primary and chemical sludges were increased and sample variability was high. The ethylbenzene concentration in the waste activated sludge was very low, a sign of probable biodegradation.

Semivolatiles. Precision data from duplicate analyses for semivolatiles of individual collected samples and from analyses of samples collected in duplicate are shown in Table 8. The average percent deviation from the mean for each sample pair was averaged with data from the other sample pairs for each priority pollutant for all feed and effluent samples. Again, sludge data were not included. Four compounds—*isophorone* and the three phenolics—showed relatively high variability for duplicate analyses of the same samples; this was attributed to limitations of the analytical methods. As expected, analyses of duplicate

Table 5—Concentrations of volatile organics in wastewater feed and effluent.

Compound	Waste-water feed		Primary clarification		Primary plus filtration		Chemical clarification		Trickling filter		Activated sludge		Aerated lagoon		Facultative lagoon	
	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ
Carbon tetrachloride	69	33	63	40	56	14	101	23	26	15	13	3	15	9	11	4
1,1 Dichloroethane	144	24	144	16	98	16	111	15	94	19	8	3	45	10	19	6
1,1 Dichloroethylene	212	72	188	69	138	43	150	47	85	31	14	11	83	59	35	49
Chloroform	135	16	143	17	113	21	106	15	102	29	18	10	53	17	31	18
1,2 Dichloroethane	153	44	135	41	96	18	109	33	93	17	22	14	45	22	15	11
Bromoform	90	35	83	37	119	30	114	26	41	24	29	10	15	6	22	26
Ethylbenzene	111	21	102	25	70	27	73	36	31	11	6	10	27	15	12	27

Table 6—Removal of volatile organics by different processes.

Compound	Primary clarification		Primary plus filtration		Chemical clarification		Trickling filter		Activated sludge		Aerated lagoon		Facultative lagoon	
	% Removal	σ	% Removal	σ	% Removal	σ	% Removal	σ	% Removal	σ	% Removal	σ	% Removal	σ
Carbon tetrachloride	19	34	22	37	-13	24	59	22	74	22	70	27	77	24
1,1 Dichloroethane	-2	17	32	9	21	14	34	12	94	2	68	4	87	4
1,1 Dichloroethylene	5	31	22	21	25	30	58	16	92	7	63	22	85	17
Chloroform	-7	15	18	9	20	15	25	18	86	9	61	11	80	7
1,2 Dichloroethane	7	14	34	9	22	31	33	16	84	10	70	14	90	7
Bromoform	18	23	2	27	-6	20	57	16	65	14	80	11	84	11
Ethylbenzene	9	18	35	28	31	34	71	9	93	13	70	21	96	5
Average removal of all volatiles	7	—	24	—	14	—	48	—	84	—	68	—	86	—

Table 7—Concentrations of volatile organics in sludges.

Compound	Primary sludge		Waste activated sludge		Trickling filter sludge		Chemical sludge	
	$\mu\text{g/L}$	σ	$\mu\text{g/L}$	σ	$\mu\text{g/L}$	σ	$\mu\text{g/L}$	σ
Carbon tetrachloride	20	10	14	4	12	5	14	4
1,1 Dichloroethane	135	30	9	2	60	32	139	14
1,1 Dichloroethylene	156	38	13	12	47	38	181	63
Chloroform	126	35	12	4	60	42	149	30
1,2 Dichloroethane	128	25	24	19	77	30	127	59
Bromoform	27	13	18	4	15	4	25	16
Ethylbenzene	312	150	3	1	28	16	511	393

samples also showed a higher variability than duplicate analyses of the same sample. The average percent deviation for duplicate analyses of the same samples for all semivolatiles, excluding isophorone and the three phenolics, was 4%. The corresponding

variability for analyses of samples collected in duplicate was 10%. The average percent deviations from mean for all semivolatiles except isophorone and the three phenolics in sludge samples were 9% for duplicate analyses and 18% for duplicate samples.

Average concentrations of semivolatile priority pollutant organics in wastewater feed and process effluents are shown in Table 9. Table 10 shows the average percent removals of each semivolatile organic from 11 matched pairs of influent and effluent samples (and three matched pairs for lindane and heptachlor). The activated sludge system was clearly superior in semivolatile removal; except for lindane and heptachlor, removals exceeded 80%. The facultative lagoon ranked second; removals for 11 semivolatiles exceeded 70%. The aerated lagoon ranked third, and primary clarification produced the lowest overall removals.

Individual semivolatiles associated with the wastewater solids were removed effectively by those treatment processes that produced effluents with low suspended solids concentrations. Chemical clarification gave high removals of bis(2-ethylhexyl)phthalate, phenanthrene, pyrene, and fluoranthene. The primary plus filtration system gave somewhat lower removals of the same four compounds. Removals by the trickling filter system were comparable to those of the primary plus filtration system for this particular mix of semivolatiles.

Concentrations of semivolatiles and TSS in sludges are shown in Table 11. Unlike the volatile organics, the semivolatiles seem

Table 8—Reproducibility of duplicate analyses of individual collected samples and analyses of samples collected in duplicate—semivolatiles.

Compound	Average % deviation from mean	
	Duplicate injections of 23 samples	Analyses of seven duplicate samples
Bis(2-ethylhexyl)phthalate	2	12
Dibutylphthalate	4	7
Naphthalene	1	12
Phenanthrene	6	15
Pyrene	2	4
Fluoranthene	2	2
Isophorone	14	15
Bis(2-chloroethyl)ether	7	16
p-Dichlorobenzene	7	9
Phenol	24	26
2,4 Dichlorophenol	36	42
Pentachlorophenol	14	10

Table 9—Concentrations of semivolatile organics in wastewater feed and effluents.

Compound	Waste-water feed		Primary clarification		Primary plus filtration		Chemical clarification		Trickling filter		Activated sludge		Aerated lagoon		Facultative lagoon	
	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ
Bis(2-ethylhexyl)phthalate	168	74	90	32	47	44	15	16	39	15	18	22	34	43	30	46
Dibutylphthalate	73	26	68	19	56	18	47	15	52	18	7	7	44	12	14	7
Naphthalene	108	34	92	33	86	11	79	9	74	15	4	1	36	5	13	6
Phenanthrene	95	24	76	35	48	5	24	6	51	14	4	1	40	12	16	13
Pyrene	104	18	84	22	39	6	12	4	48	10	5	2	36	11	25	11
Fluoranthene	104	19	80	21	39	5	13	5	49	13	5	2	36	10	23	10
Isophorone	89	30	77	19	74	19	80	21	72	35	2	1	68	29	62	18
Bis(2-chloroethyl)ether	143	51	122	37	120	26	114	53	132	37	30	48	102	41	78	28
p-Dichlorobenzene	93	17	75	24	66	17	66	20	58	16	5	3	31	7	12	6
Phenol	126	49	112	70	131	42	99	72	64	45	14	6	84	55	18	19
2,4 Dichlorophenol	228	178	133	105	300	226	92	45	200	197	1	1	155	202	65	95
Pentachlorophenol	84	46	78	50	90	63	50	39	82	48	3	2	57	48	20	8
Lindane	39	6	40	11	—	—	32	2	34	3	31	2	22	1	7	2
Heptachlor	39	3	26	1	—	—	14	1	18	1	13	1	13	2	13	1

to associate with the solids in the process sludges. Concentrations are much higher than those in the process effluents with which they were in equilibrium. The four compounds that had high removals by chemical clarification were highly concentrated in both the chemical sludge and the primary sludge. There were also high concentrations of bis(2-ethylhexyl)phthalate in the waste activated sludge, but much lower concentrations of the three polynuclear aromatic hydrocarbons (PAH). The PAH compounds seemed to be biodegraded much faster than the high molecular weight phthalate. The dibutylphthalate biodegraded rapidly as evidenced by the much lower concentration in the waste activated sludge. Similarly, the other semivolatiles seemed to be biodegraded in the activated sludge process; they were effectively removed but were not highly concentrated in either primary sludge or waste activated sludge. The 2,4 dichlorophenol concentration in the primary sludge was not sufficient to account for the calculated 45% removal in primary clarification. This discrepancy and the high variability of the multiple analyses

shown in Table 8 indicate that data obtained for this compound were inaccurate.

Metals. Average concentrations of selected toxic metals in wastewater feed and process effluents are shown in Table 12. Metals data were not collected for the chemical clarification and primary plus filtration systems. Concentrations were variable because metals were not spiked. Metal removals by the pilot processes calculated from the average concentrations of Table 12 and shown in Table 13 were somewhat higher than mean removals reported in a 1977 survey of a large number of full-scale trickling filter and activated sludge plants.⁹ The activated sludge system and facultative lagoon showed the best removals of metals just as they did for the organics. Metal concentrations in sludges are shown in Table 14. With the exception of cadmium, metal concentrations in the sludge were generally much higher than concentrations of semivolatile organics because of higher concentrations of metals in the influent and biodegradation of the organics.

Table 10—Removal of semivolatile organics by different processes.

Compound	Primary clarification		Primary plus filtration		Chemical clarification		Trickling filter		Activated sludge		Aerated lagoon		Facultative lagoon	
	% Removal	σ	% Removal	σ	% Removal	σ	% Removal	σ	% Removal	σ	% Removal	σ	% Removal	σ
Bis(2-ethylhexyl)phthalate	37	33	75	13	89	14	75	9	87	16	77	29	80	31
Dibutylphthalate	2	20	22	15	31	20	26	16	88	17	40	20	78	13
Naphthalene	13	23	20	19	23	16	28	16	97	1	64	12	87	8
Phenanthrene	21	21	49	14	74	7	45	15	95	2	55	19	82	19
Pyrene	18	21	61	8	88	4	54	8	95	2	63	14	75	12
Fluoranthene	22	20	61	8	87	4	53	11	95	2	64	15	77	11
Isophorone	4	17	8	21	5	25	17	36	98	1	22	37	25	32
Bis(2-Chloroethyl)ether	6	27	20	28	17	40	-1	16	80	31	23	31	43	14
p-Dichlorobenzene	19	18	29	19	28	19	36	18	94	3	65	13	87	6
Phenol	23	48	4	33	21	56	50	29	86	9	30	42	86	11
2,4 Dichlorophenol	45	24	-4	6	60	15	31	33	99	1	48	46	73	38
Pentachlorophenol	16	28	19	36	50	38	4	6	96	2	37	36	74	12
Lindane	-4	25	—	—	17	10	13	11	18	16	42	12	80	4
Heptachlor	32	7	—	—	64	3	53	4	65	3	66	5	62	6

Table 11—Concentrations of semivolatile organics and TSS in sludges.

Compound	Primary sludge		Waste activated sludge		Trickling filter sludge		Chemical sludge	
	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ
Bis(2-ethylhexyl)phthalate	5 550	3 450	4 350	3 630	1 425	860	9 900	5 850
Dibutylphthalate	1 150	850	284	474	356	157	3 100	2 050
Naphthalene	620	490	29	26	230	66	1 180	715
Phenanthrene	2 850	2 010	184	165	820	304	5 925	3 425
Pyrene	4 000	2 750	366	254	1 140	620	8 550	4 575
Fluoranthene	4 000	2 950	337	226	1 040	525	8 250	4 350
Isophorone	70	34	19	6	106	52	84	76
Bis(2-chloroethyl)ether	129	81	115	68	262	115	152	62
p-Dichlorobenzene	580	515	36	17	169	80	1 150	740
Phenol	465	545	565	780	395	291	358	257
2,4 Dichlorophenol	199	102	ND*	ND*	483	225	464	569
Pentachlorophenol	119	69	110	131	174	145	1 175	1 260
Lindane	1 010	640	204	69	240	148	707	127
Heptachlor	1 180	208	658	201	383	116	1 967	208
TSS (mg/L)	19 850	8 550	6 625	1 035	2 250	1 250	18 600	8 375

* ND = Not detected.

Table 12—Concentrations of metals in wastewater feed and effluents.

Metal	Wastewater feed		Primary clarification		Trickling filter		Activated sludge		Aerated lagoon		Facultative lagoon	
	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ	µg/L	σ
Cr	221	88	206	135	107	130	40	18	65	106	46	34
Cu	345	119	278	113	137	77	61	40	89	61	71	46
Ni	141	93	136	101	98	68	81	45	91	50	81	59
Pb	165	168	115	102	86	79	58	75	70	76	82	110
Cd	25	23	22	14	18	14	19	17	—	—	17	9

Table 13—Percent removal of metals by different processes.

Metal	Primary clarification	Trickling filter	Activated sludge	Aerated lagoon	Facultative lagoon
Cr	7	52	82	71	79
Cu	19	60	82	74	79
Ni	4	30	43	35	43
Pb	30	48	65	58	50
Cd	12	28	24	—	32

Table 14—Concentrations of metals in sludges.

Metal	Primary sludge		Waste activated sludge		Trickling filter sludge	
	mg/L	σ	mg/L	σ	mg/L	σ
Cr	15.6	6.9	12.8	13.6	5.6	4.6
Cu	23.5	9.2	14.9	12.6	7.0	4.8
Ni	5.2	2.9	3.5	2.8	2.0	1.6
Pb	10.1	4.6	5.3	4.6	2.7	2.4
Cd	0.6	0.5	0.4	0.5	0.2	0.1

SUMMARY

This research evaluated the capabilities of five less-than-secondary treatment processes for removal of priority pollutants, and determined how the organics partition and interact within the processes. A conventional activated sludge system was operated in parallel with the alternative processes to provide a control against which the alternative processes could be compared.

The control activated sludge process provided the best removals of both conventional pollutants and toxic priority pollutants. The facultative lagoon with its long detention time was the most successful alternative process. The aerated lagoon with

a shorter detention time was less effective than the facultative lagoon. Nonetheless, a modified design that permits higher aeration rates should increase the efficiency of organic priority pollutant removal, particularly of volatiles.

The high rate trickling filter system was less effective than the lagoons. Design and operating changes, such as reduced flow or forced draft ventilation, could be used to increase the pollutant removals in the trickling filter system. The chemical clarification system and the primary plus filtration system removed only those toxics associated with wastewater solids; these two systems would not be good choices for removal of toxic priority pollutants.

In general, the alternative processes do not produce overall toxics removals comparable to activated sludge treatment. However, selected alternative processes may be acceptable in site-specific situations, where toxic removal requirements are limited because of consistently low influent concentrations of toxic chemicals and where water quality criteria are not overly restrictive.

ACKNOWLEDGMENTS

Credits. Richard Dobbs and Michael Jelus of the Water Engineering Research Laboratory and Margaret Koczwara and other University of Cincinnati operations staff at the Test and Evaluation Facility assisted with this research.

Authors. Sidney Hannah and Barry Austern are research chemists for U. S. EPA. Robert Wise (deceased) was a research chemist for U. S. EPA at the time of this study. Atal E. Alp is chief of Pilot Plant Research Staff, U. S. EPA. Correspondence should be addressed to S. A. Hannah, U. S. EPA, 26 W. St. Clair St., Cincinnati, OH 45268.

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